A Low Cost ECG Monitoring System with ECG Data Filtering

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***Abstract*— The ElectroCardioGram (ECG), a set of graphs of electrical heart activity, is the principle tool used in diagnosis of different heart conditions. This paper illustrates the design and implementation of a low-cost ECG monitor using microcontroller, Arduino programming language and Raw ECG data filtering with different digital filters. This paper describes the development of accurate monitoring of a heart rate based on a microcontroller. We can record the ECG signals and Heart beats of all patients in a single computer. These biomedical signals are acquired and then processed with a microcontroller. For the patient suffering from the cardiac disease it is very necessary to perform accurate and quick diagnosis. For this purpose a continuous monitoring of the ECG signal, patient's current heart rate and BP is essential. We can monitor the patient's ECG signal by using Arduino board and ECG shield and receive in the central place in any hospital. We use the C/C++ programming to retrieve the ECG data obtained from the human body. We filter the data with different digital filters to remove noise form the ECG data and store the data into a text file. Those data can be plotted to have ECG waveform to diagnosis heart problems.**

Keywords- Electrocardiogram, ECG signal, FIR Filters, High-pass Filter, Low-pass Filter, Microcontroller

I. INTRODUCTION

The ECG monitoring system generally reflects the electrical activity of human body. The cardiovascular diseases are measured from the ECG based on the abnormality in the parameters of that graph. Different parameters denote different level of cardiac problems. It is necessary to pass the ECG data to a specialist person. As this data is so sensitive in patient's perspective, in wrong hand it can be devastating for them.

An electrocardiogram is a test that checks for problems with the electrical activity of heart. It checks the abnormality of heart. It results from diastole and systole phases of heart. Diastole and systole represent the resting or filling phase of a cardiac chamber and the contracting or pumping phase, respectively. The characteristics of the ECG signal, including the heart rate, the PR interval, the QRS duration, the QT interval, etc., are the important evidence for doctors to diagnose diseases. The change in these parameters indicate illness of heart. If there happens any variation to process the ECG waveform it may cause misdiagnosis. So it is very essential to process the ECG waveform with a great care so that we get the real ECG waveform. After the collection of ECG data it is very much essential to filter those data because those data may contain noise and unwanted data. Thus, the target of ECG filtering is to reduce the redundancy as much as possible while to maintain clinically acceptable signal quality [1] [2].

Filtering is the process of removing unwanted data form a signals. It refers to removing noise and amplifying some data to get the actual data. Some common filters are used to remove the noise and unwanted data from ECG data. Low-pass filter, High-pass, FIR filter and QRS detection algorithm are used to have the actual ECG waveform form those actual ECG data are collected form human body through Microcontroller Based system. In this paper Low-pass, High-pass and FIR filters are used to remove the unwanted data and QRS detection algorithm is used for making the ECG waveform smoother.

II. LITERATURE REVIEW

ECG devices are used to asses heart rhythm (rate and regularity of heartbeats), measure sizes position of chambers, also the presence of any damage of heart and the effects of the heart. To diagnose poor blood flow to the heart muscle, heart attack ECG devices are used. Devices such as Pacemaker are used to regulate the heart.

Electrocardiography (ECG or EKG from Greek: kardia, meaning heart) is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the surface of the skin and recorded by a device external to the body [3]. The recording produced by this noninvasive procedure is termed an electrocardiogram (also ECG or EKG) ECG devices are performed to diagnosis or research about human heart; they are also used on animals for research and non-nature research.

ECG data are useful for research. Storing the ECG data can be very handy for the further use. But raw ECG data may include

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some noise, baseline wonder. This causes complexity for ECG data usage. Applying different filters can eliminate those constraints.

Masaki Kyoso proposes a simple algorithm to detect abnormal ECG. The algorithm is composed of a baseline drift canceller (utilizing a moving average calculation), a waveform detector (using a modified second order derivative) and an ECG analyzer[4].

F. Buendía-Fuentes, M. A. Arnau-Vives, A. Arnau-Vives propose a High-Bandpass filtering technique for ECG data to remove baseline wonder. They try to find out the error in the interpretation of ST segment [19].

S. Sundar, S. Karthick and S. Valarmathy implementss FIR filter with Canonical Signed Digit (CSD) to remove noise from ECG data. They present the study of FIR filter using common subexpression elimination techniques for ECG signal Processing [5].

III. System Implementation and Data Filtering

In this research we attempt to design a microcontroller based ECG embedded system, especially for diagnosis of heart related problems using some hardware toolkit for rural medical center of Bangladesh. For this proposed system here we have to use a hardware toolkit, which is capable of measuring daily health conditions of electrocardiogram (ECG) and this digital signal is transfer to a receiving device for signal processing and we using EKG shield for convert them as usable form of binary data. We just collect the ECG data and filter it using different ECG data filtering algorithm (like: Low-pass filter, High-pass filter, FIR filter). Then this raw data will be used for prescribe medicine by the cardiac specialist by the signal showing curve.

System Model: In this project we have tried to design, develop and implement a system that will create the initial step towards a low cost microcontroller based ECG measurement system which can be a great solution for the welfare of the rural people in terms of their cardiovascular diseases. During this phase of that proposed system we have sent data from human body to a computer situated at the rural health care center using Arduino ECG-EKG shield. In that purpose we have to use Arduino Programming Language (widely known as "Micro C") to create an interface between the microcontroller based ECG device and a USB communication port of that computer.

When ECG data started coming from the human body through the shield, we have written a program in C programming language to receive those data from the COM port and save them in a .txt for further use.

In that sense, we can divide the implementation procedure of our project into several phases. They are as following:

1. Hardware Setup
2. Interfacing between Arduino Shield and USB port of the computer
3. Reading serial data from the COM port
4. Storing those data into a text file
5. Filtering the data using ECG data filtering algorithms

The stored data from the human body can be used for various purposes in future. As per the proposed system the data will be sent to the doctor's smartphone or any other portable device which will create an ECG waveform in that device. From the created graph the specialist physician will be able to diagnosis the cardiovascular condition of the patient and prescribe instantly as well. As a result after implementation of this system, the distance between the rural patients and the doctors will be lessen and it will have a significant impact on the national healthcare condition.

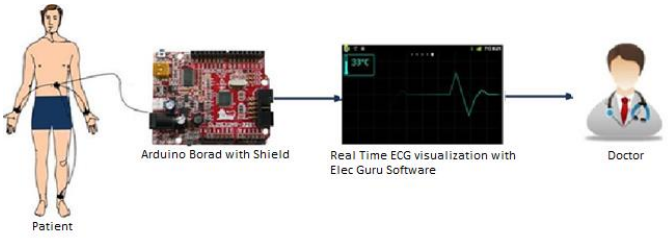

Figure 1: Real-time ECG measurement system

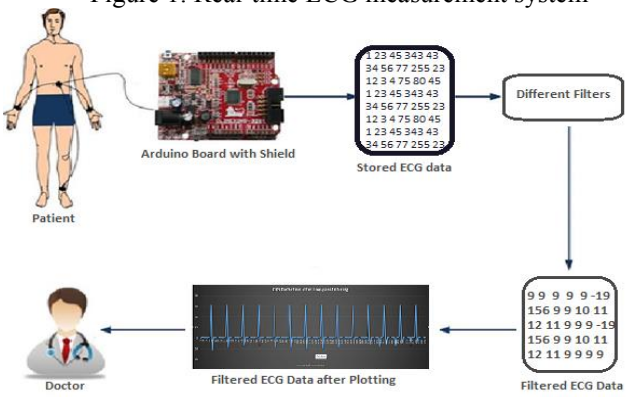

Figure 2: Filtering Raw ECG Data

Hardware Setup: Setting up the hardware equipment is a critical and sensitive step of the implementation procedure. We had to take this step so cautiously because if the board is exposed to high electrostatic potentials then any kind of permanent damage can be occurred. There are three Hardware equipment needed to implement this project.

1. Arduino Compatible Board (Ex. Olimexino-328)
2. Shield EKG-EMG (Ex. Olimax EKG Shield)
3. Electrode Cable (Ex. EKG-EMG PA)

Shield EKG-EMG is the major hardware product of this project. It is built by the Olimex group. It is a microcontroller based board which is being added to an Arduino compatible

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board to make a device to measure the heart rate of human body.
For the purpose of this project, we have used Olimexino-328 Arduino compatible board.Olimaxino-328 is compatible both with Olimax EKG shield and EKG-EMG Pa electrode cable. Electrode cable is connected to the human body in order to response to the electric signal of the human body.

Electric Guru Software to visualize real-time ECG: We use Electric Guru Software toolkit to represent the pulses of heart as signal. Our heartbeats are rated into the signal by this software. Arduino IDE communicates with the software through the serial communication port. Binary data bits are generated according to the pulse signal. Every signal rounds up to one cycle and again start.

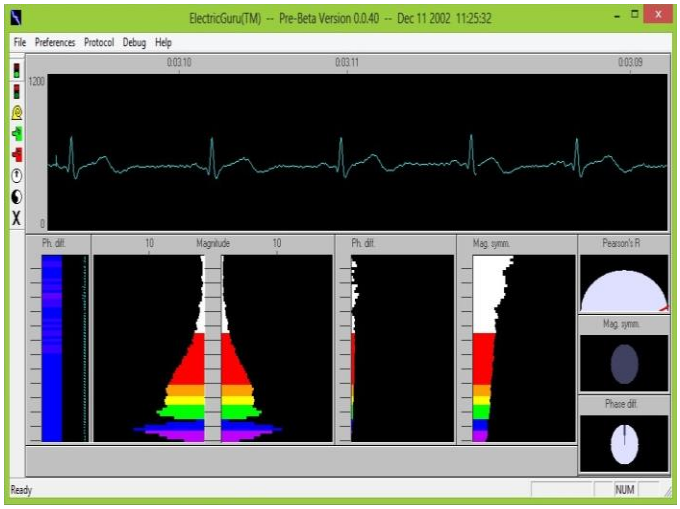

Figure 3: ElecGuru Software for real-time ECG visualization

Reading and Storing Data from Serial Port: We used C programming language in order to read the ECG data from the serial port. We wrote programs using the C Library for serial operation in order to fetch the ECG data. We also use file manipulation operations of C to store those data in a text file of local computer.

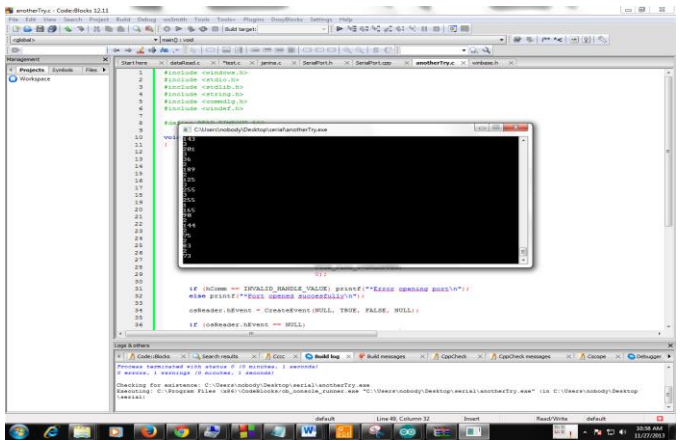
Figure 4: Reading and storing ECG data using C programming

Filtering the stored ECG data using digital filters:
Stored data may contain Baseline wander, Power line interference and muscle noise. To eliminate those noise we apply different filters including High-pass filter, FIR filter, Low-pass filter and QRS detection algorithms. Using of those filters certainly make the ECG data more practical and functional.

Low-Pass Filter: A Low-pass filter is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency [6][10]. The amount of attenuation for each frequency depends on the filter design.
We use the Low-pass filter for limiting the ECG data sample and smoothing the ECG curve [8]. In this Low-pass ECG data filtering system we collect the ECG data from the Arduino and sample the data set with some parameter [9]. We remove the value from the data set that seems noise. We put the data set into a limited range. We implemented the Low-pass filter in C++ and filtered the ECG data.

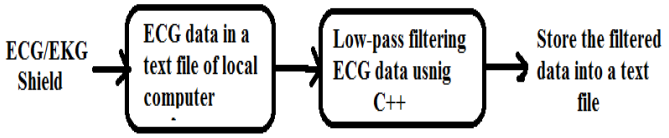

Figure 5: Implementing Low-Pass filter for ECG data

Low pass filter can mitigate the muscle noise.

High-pass Filter: Basically we implement a High-Pass filter to cut of the lower-frequency components such the baseline wander [20, 21].

Figure 6: Implementation of High-Pass filter for ECG data

Most biological signals must be processed for adequate recording. High-pass filters may distort the shape of the recorded signal and sometimes may cause electrocardiographic changes simulating myocardial ischemia. High-pass filters cut off the low frequency and let the high frequency pass by [19].

FIR Filter using Hanning window: A finite impulse response (FIR) filter has a unit impulse response that has a limited number of terms [12]. FIR filters are generally realized non recursively, which means that there is no feedback involved in computation of output data [11]. The output of the filter depends only the present and past input. The difference equation is:

$$Y(nT) = \sum_{k=0}^{N} bk\ x(nT - kT)$$

And a transfer function of this filter is given bellow:

$$H(z) = b0 + b1z\text{-}1 + b2z\text{-}2 + \ldots.. + bNz\text{-}N$$

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Most common simplest smoothing filter which reduces the high frequency noise is Hanning filter [16]. By difference equation the Hanning filter computes a weighted moving average. We have the difference equation representing the numerical algorithm for implementing a digital filter. Hanning filter equation is:

$$y(nT) = 1/4\,[x(nT) + 2x(nT - T) + x(nT - 2T)]$$

Hannig filter can be implemented by writing a computer program in C++ language where data has previously sampled and store in a text file [17]. This program directly filter the digital ECG data.

QRS Detection Algorithm: QRS detection algorithm is a technique which helps to detect the QRS complex of the ECG signal. Preprocessing and decision are the two different stage of QRS detection algorithm [13]. In preprocessing step ECG data pass a block of filter to remove the noise. Than in decision step the examined or predefined ECG data compares filtered ECG data for detecting the QRS complex wave [14] [15].

Here we first go through the Low-pass filter in preprocessing step of QRS detection [16]. Then we compare the ECG data set with the collected data set means predefined ECG data for QRS complex detection in decision step. For QRS complex detection, here we take the baseline data as a "Q" data, peak value as "R" data and the lowest value as "S" data.

Now we also determine the QRS complex after FIR filtering of ECG data.

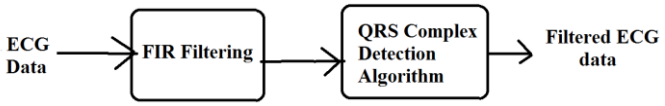

Figure 7: Implementing FIR filter for ECG data and Applying QRS detection

By this QRS detection we can filter any ECG data but we must have a standard ECG dataset to compare and to remove those abnormal data from the dataset [7]. It is very useful for getting the actual ECG data

Advantage of those filters:
Microcontroller based ECG measurement system is not noise free. There are some noise and unwanted data mixed in the dataset that we collect from the human body. So it is essential to remove those noise and unwanted data from the dataset to get the actual ECG data. The advantages of using those filters are given:

1. The Low-pass filter is used to remove the unwanted spike (data that is not peak value R) from the dataset
2. Applying QRS filtering algorithm to detect the QRS data from the dataset.
3. FIR filter is a digital filter which is more accurate than analog filter [17].
4. FIR filter has a linear phase characteristic so that it can remove the baseline wander and power line interference [18].
5. QRS detection algorithm is more important because the energy of the heart bit located on the QRS complex [13].

IV. Result Analysis and Discussion

This project aims basically on extracting the data from human body which is being used to measure the ECG wave by Arduino EKG-EMG shield. In order to analyze the ECG data of human body from different ages, we have investigated this system on different people. We have got following result based on that investigation.

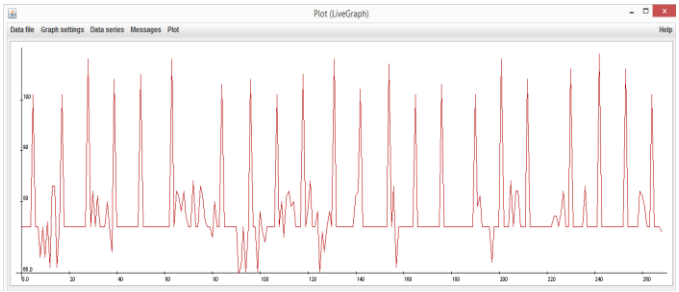

Figure 8: Raw ECG data plotted on Live Graph Software

From figure-8, we have seen that raw ECG data have noise and baseline wander. We found a minimum similarity with actual ECG graph. But after applying those filters on the same ECG data we got significant changes which is shown in figure-9. The obtained outcome is very close to actual ECG data and it became more reliable to know the cardiac health situation of patients.

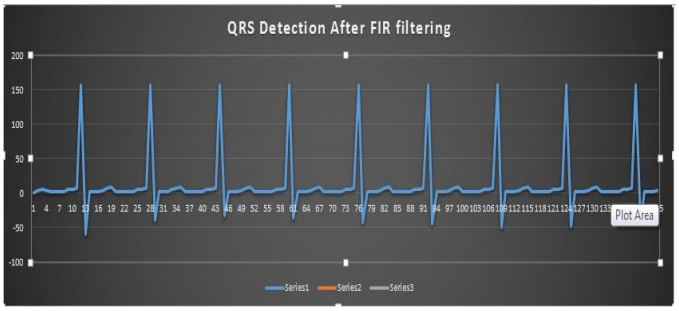

Figure 9: ECG graph after filtering and QRS detection

If we can find the number of errors, it can be a significant way to extract and store the heart rate data of human body. We tried to filter those ECG data using different filters for removing the noise form the ECG data. Further research can contribute to the improvement of this process and make it more accurate.

V. Conclusion

For rural medical center, a microcontroller based ECG system is distributed information system to connect rural patients to

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cardiac specialists. Therefore, it is of significance to consider interoperability of ECG systems not only in rural people but also for the personal use. We mostly focus the project utilization in one's own diagnosis of cardiac problem by oneself. Home medical diagnosis encourages this ECG embedded system.

Available use of device will ensure the diagnosis of any type of cardiac problem by the communication to the cardiac specialist within a short time. Filtered ECG data can be very useful for the cardiac specialist to detect anomalies regarding cardiac problems. In future more filtering is needed to have the exact ECG waveform. These are some basic filters that are used to clarify ECG data from noise and baseline wander. This system needs more research for getting exact ECG waveform.

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